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UNDERSTANDING PELAGIC STINGRAY (*PTEROPLATYTRYGON VIOLACEA*) BY-CATCH BY SPANISH LONGLINERS FROM THE MEDITERRANEAN SEA

José C. Báez[1], Guillermo Ortuño Crespo,
Salvador García-Barcelona, José M. Ortiz de Urbina, José M. de la Serna & David Macías

SUMMARY

The pelagic stingray Pteroplatytrygon violacea *is known to be a frequent by-catch in longline fisheries around the world. The aim of this study is to analyze the parameters affecting to the by-catch of pelagic stingray by the Spanish surface drifting longline fleet that operates in the Mediterranean Sea. Since the year 2000 until the year 2013, 3007 longline fishing operations were monitored. In these 14 years, we recorded 57,574 pelagic stingrays by-catches by Spanish longline. Two gear types concentrate 96.05% of pelagic stingray by-catch observed: traditional surface longliners targeting swordfish (LLHB) and surface drifting longliners targeting albacore (LLALB). We obtained two statistically significant explicative models for the gears LLHB and LLALB. In both cases, fisheries over continental shelf and summer variables are important parameters. Furthermore, for the LLHB explicative model included the variables: number of hooks, latitude where the setting started, Distance between both extremes of the longline and spring. Moreover, for the LLHB we obtained a relationship between the Capture per Unit of Effort of pelagic stingray from favour sets per year and the North Atlantic Oscillation in winter.*

RÉSUMÉ

*Il est notoire que la pastenague violette (*Pteroplatytrygon violacea*) est fréquemment capturée en tant que prise accessoire par les pêcheries palangrières dans le monde entier. Cette étude poursuit l'objectif d'analyser les paramètres affectant la prise accessoire de pastenague violette par la flottille espagnole de palangre de surface dérivante active en mer Méditerranée. Depuis l'année 2000 jusqu'en 2013, 3.007 opérations de pêche à la palangre ont été suivies. Au cours de ces 14 années, 57.574 prises accessoires de pastenague violette réalisées par des palangriers espagnols ont été enregistrées. Deux types d'engin concentrent 96,05% de la prise accessoire observée de pastenague violette : la palangre de surface traditionnelle ciblant l'espadon (LLHB) et la palangre dérivante de surface ciblant le germon (LLALB). Nous avons obtenu deux modèles explicatifs statistiquement significatifs pour les engins LLHB et LLALB. Dans les deux cas, les pêcheries réalisées le long du plateau continental et les variables estivales sont des paramètres importants. De plus, en ce qui concerne la LLHB, le modèle explicatif incluait les variables suivantes : nombre d'hameçons, latitude du départ de l'opération, distance entre les deux extrémités de la palangre et le printemps. De plus, dans le cas de la LLHB, nous avons obtenu une relation entre la prise par unité d'effort de la pastenague violette des opérations positives par an et l'oscillation Nord-Atlantique en hiver.*

RESUMEN

*Se sabe que la raya látigo violeta (*Pteroplatytrygon violacea*) es captura fortuita frecuente en las pesquerías de palangre pelágico de todo el mundo. El objetivo de este estudio es analizar los parámetros que afectan a la captura fortuita de la raya látigo violeta por parte de la flota de palangre de deriva superficie española que opera en el Mediterráneo. Desde el año 2000 hasta el año 2013, se hizo un seguimiento de 3007 operaciones pesqueras de palangre. En estos 14 años, se ha consignado la captura fortuita de 57.574 rayas látigo violeta por parte del palangre español. Dos tipos de arte concentran el 96,05% de la captura fortuita de raya látigo violeta observada: los palangreros tradicionales de superficie que se dirigen al pez espada (LLHB) y los palangreros de superficie de deriva que se dirigen al atún blanco (LLALB). Se obtuvieron dos modelos explicativos estadísticamente significativos para los artes LLHB y LLALB. En ambos casos, las pesquerías sobre la plataforma continental y las variables estivales son parámetros importantes. Además, para el modelo explicativo de LLHB se incluyeron las siguientes variables: número de anzuelos, latitud cuando se inició el lance, distancia entre ambos extremos del palangre y primavera. Asimismo, para LLHB se obtuvo una relación entre la captura por unidad de esfuerzo de la raya látigo violeta de los lances positivos por año y la oscilación del Atlántico norte en invierno.*

KEYWORDS

By-catch, Dasyatis violacea*, Longline, Pelagic stingray,* Pteroplatytrygon violacea

[1] Instituto Español de Oceanografía, C.O. Málaga. Pto . Pesquero s/n, 29640, Fuengirola, España. E-mail: jcarlos.baez@ma.ieo.es

1. Introduction

The elasmobranchs are long-lived animals with slow growth and late maturity (Musick, 1999). The elasmobranchs fisheries mortality has been recognised as a main factor potentially affecting to the decline of populations (Ferretti et al., 2008). For this reason, it is important disentangle the factors determining by-catch and to identify which management and conservation actions are useful to mitigate the negative effect of fisheries. According to a recent Food and Agriculture Organization of the United Nations (FAO) report (Bradai et al., 2012) the Mediterranean Elasmobranchs including sharks, rays and chimaeras, are by far the most endangered group of marine fish in this area, mainly due to overfishing.

The pelagic stingray *Pteroplatytrygon violacea* (Bonaparte, 1832) (Dasyatidae), synonym of *Dasyatis violacea*, distributes in circumpolar and subtropical areas including Mediterranean Sea. *Pteroplatytrygon violacea* is the only species of stingray known occupying pelagic waters (for example Mollet, 2002; Veras et al., 2008). Despite their lack of commercial value, pelagic stingrays are known to be caught in great numbers as by-catch in longline fisheries around the world (Domingo et al., 2005). Thus, studies have shown how the geospatial overlap between this species habitat and important longline fishing grounds has resulted in large by-catch numbers with unknown effects to the population and ecosystem structure (Domingo et al., 2005; De Siqueira and De Sant'Anna, 2007).

The Western Mediterranean is an important fishing ground for the Spanish drifting longline fleets which target swordfish (*Xiphias gladius*), albacore tuna (*Thunnus alalunga*) and bluefin tuna (*Thunnus thynnus*). Briefly the main gears used for the surface drifting Spanish longliners are: LLALB (longline albacore), surface longline targeting albacore; LLAM (longline American), surface longliners using a hydraulically-operated monofilament longline reel and targeting swordfish; LLJAP (longline Japanese), surface longliners targeting bluefin tuna; and LLHB (longline home-base), traditional surface longliners targeting swordfish. The principal differences in longline gears are related to hook type and hook size, bait type and operational depth. A major description of these gears and fisheries are available in Camiñas et al. (2006), Báez et al. (2007a, b) and García-Barcelona et al. (2010a, b).

The previous studies done in the Western Mediterranean Sea reported that the pelagic stingray are the most commonly caught elasmobranch as by-catch in LLALB and the second most common elasmobranch catch in LLHB (Filanti et al., 1986, Di Natale et al., 1995, Orsi Relini et al., 1999 in Baum et al., 2009), with a low discard survival rate due to damage to jaws and mouth (Baum et al., 2009). In the case of Spanish longline vessels there are significant differences between years and gears. Thus, Rey & Alot (1984) reported the results of a swordfish longline survey in Mediterranean Spanish waters, and recorded only two pelagic stingrays in 11 fishing operations. According to Macías et al. (2004) the 8% of number of individuals captured by Spanish longline were pelagic stingray, while Báez et al. (2009) suggest that about 68% of number of individuals captures by Spanish artisanal longline were pelagic stingray.

Despite the differences in previous observations, and the important potential impact of longline fisheries on pelagic stingray population, there are scarce studies over the by-catch of this species. Moreover, there are not studies about temporal oscillation of by-catch events.

The aim of this study is to further increase the knowledge about the eco-geographical parameters and temporal oscillation which contribute to the by-catch of *Pteroplatytrygon violacea* by the Spanish surface drifting longline operating in the Western Mediterranean Sea. This study seeks to explore more in depth the conditions which trigger the high by-catch rates of this species and suggest how they could be reduced.

2. Material and Methods

Since the year 2000, on-board scientific observers compiled pelagic stingray by-catch data from drifting longline vessels per gear types. The collection of this data was conducted following the recommendations of the International Commission for the Conservation of Atlantic Tunas (ICCAT). The data series used in this study comprises the period from 2000 to 2013.

For each fishing set observed, data was recorded on fishing set location, time of setting and hauling; environmental data (i.e. sea surface temperature, distance to the coast, depth and weather conditions, moon phase); soaking duration; gear characteristics (i.e. total length, mean depth, number of hooks, etc.); type and size of bait; species composition; and corresponding biological information (i.e size and weight). Within each set sampled, observers monitored 100% of the total hooks retrieved and recorded information on species composition, number and estimated weight of both target species and by-catches including pelagic stingray.

Given than 96.05% of the on-board by-catch data affecting pelagic stingrays was found on the gear types LLHB and LLALB, this study funneled its attention towards the by-catch that took place in these two gear types. Moreover, pelagic stingrays are known to inhabit the water column at depths which do not exceed 100 meters; both the LLHB and LLALB gear types operate at depths shallower than 100 meters and therefore overlap with their habitat (Wilson & Beckett, 1970):

- LLHB is used year-round and comprised of 1,500 to 4,000 hooks; these are normally baited with mackerel (*Scomber* sp.) and squid (*Illex* sp.). LLHB hooks are J-shaped Mustard #2 (approximately 7.5 x 2.5 cm) (Báez et al. 2013a) (**Figure 1**).
- LLALB is primarily used from May until October and is the shallowest of all surface longlines. The LLALB gear type also uses J-shaped hooks, however, these are Mustard #5 (approximately 5 x 2 cm) (Báez et al. 2013b) (**Figure 2**).

With regards to pelagic stingray, the objectives of observers were to record captures and identify specimens to the lowest taxonomic level possible. However, at the beginning of the temporal series, as the observers had little experience with pelagic stingray, many specimens could not be identified and /or recorded at species level; nevertheless, the accuracy of the data improved gradually, reaching a high degree of precision.

Pelagic *Pteroplatytrygon violacea* and demersal *Dasyatis pastinaca* (Linnaeus, 1758) present significantly similar morphological characteristics, which makes their taxonomic classification quite difficult. Both species have been reported to be present in the Mediterranean Sea, however, they inhabit very different habitats (pelagic water column *vs.* near bottom demersal) (Froese & Pauly, 2011). This ecological difference was used in this study in order to reduce the possibility of misidentifying *Pteroplatytrygon violacea* which inhabit only epipelagic waters. For this reason we decided to limit the gear analysis to LLHB and LLALB.

2.1 Data analysis

We calculated annual pelagic stingray by-catch rates in LLHB and LLALB as Catch Per Unit of Effort (CPUE) (total number of individuals caught in a year divided by the thousands of hooks deployed that year).

We performed a binary logistic stepwise forward/backward regression of the presence and absence of pelagic stingray by-catch to test whether the probability of incidentally catching a pelagic stingray (1 or more) may be forecast by some of these explanatory variables listed in **Table 1**.

Many authors recommend the use of logistic regressions for evaluating the effects of environmental conditions and fishing practices on the probability of interactions with by-catches (for example Báez et al., 2014a and references therein), and it could relate the probability of an event (for example, the risk of catching a specimen of pelagic stingray) with a series of variables and explanatory factors.

By performing a logistic regression of the by-catch presence/absence on each variable separately, we selected a subset of variables significantly related to the distribution of the by-catch. To control for the increase in type I error due to multiple tests (to see Báez et al., 2014a), we only accepted those variables that were significant under a False Discovery Rate (FDR) of $q<0.05$, using the Benjamini and Hochberg procedure. We then performed forward stepwise logistic regression on the subset of significant predictor variables to obtain a multivariate logistic model.

Model coefficients were assessed by means of an omnibus test and the goodness-of-fit between expected and observed proportions of by-catch events along ten classes of probability values and evaluated using the Hosmer and Lemeshow test (which also follows a Chi-square distribution; low P-0.05 would indicate lack of fit of the model) (Hosmer & Lemeshow, 2000). On the one hand, the Omnibus test examines whether there are significant differences between the -2LL (less than twice the natural logarithm of the likelihood) of the initial step, and the -2LL of the model, using a Chi-squared test with one degree of freedom. On the other hand, the Hosmer and Lemeshow test compares the observed and expected frequencies of each value of the binomial variable according to their probability. In this case we expected that there are no significant differences for a good model fit.

In addition, the discrimination capacity of the model (trade-off between sensitivity and specificity) was evaluated with the receiving operating characteristic (ROC) curve. Furthermore, the area under the ROC curve (AUC) provides a scalar value representing the expected discrimination capacity of the model.

In a second step, we standardized the CPUE using the explicative model per year. Thus, we used the fisheries operation that fisheries under similar eco-geographical variables that show explanation power in the final model for LLHB and LLALB gears. The CPUE standardized per year is analyzed in relation with the North Atlantic Oscillation. The Mediterranean climate displays a great interannual variability closely related to atmospheric oscillation patterns (Vicente-Serrano and Trigo, 2011). In this context, the North Atlantic Oscillation (NAO) is responsible for most of the climatic variability in the North Atlantic region, modifying direction and intensity of westerlies, and the location of anticyclones (Vicente-Serrano and Trigo, 2011).

Monthly NAO index values were taken from the website of the National Oceanic and Atmospheric Administration (NOAA website: Available at http://www.cpc.noaa.gov/products/precip/CWlink/pna/nao index.html. Accessed 15 May 2014). The atmospherics oscillations present strong inter-annual and intra-annual variability (Hurrel, 1995), in this study we used the mean winter NAO in previous year to the by-catches, from October to December (NAOw).

To test the possible effect of NAOw on the CPUE of pelagic stingray, we used the CPUE from favourable sets per year (fCPUE). For this reason, we used for LLHB and LLALB, the sets only when the variables in the model were favour. We ordered fCPUE per year from lowest to highest values, and calculate their median. We assigned 1 to those years showing a fCPUE value over the median value and 0 to the years showing a fCPUE value under the Median. Binary logistic models were performed in function of the NAOw.

3. Results

Since the year 2000 until the year 2013, 3007 longline fishing operations were monitored in 68 different fishing vessels. In these 14 years, we recorded 57,574 pelagic stingrays by-catches by Spanish longline, mainly (55,301 individuals) by the LLHB (**Figure 3**) and LLALB (**Figure 4**). The CPUE of these two gears was 14.237 and 3.316 respectively. We observed highlight prevalence. Thus, in LLHB observed a prevalence of 904/1387 (65.2%), while in LLALB observed a prevalence of 510/853 (59.7%). The number of caught specimens per fishing operation fluctuated between zero and 505 (average of 27 individuals), while in LLALB fluctuated from 0-148 (average of 8).

3.1 General Logistics Models (GLMs)

We obtained two statistically significant logistic models for the gears LLHB and LLALB. For the LLHB we obtained a model with the variables: number of hooks (NH), latitude where the setting started (LATSS), fisheries over continental shelf (SCS), Distance between both extremes of the longline (DL), Spring (SPR) and Summer (SUM). The model's goodness-of fit-was significant according to the Omnibus test (Omnibus test= 165.343, df= 6, P< 0.0001; Hosmer and Lemeshow test= 11.272, df= 8, P= 0.187), and its discrimination capacity was good (AUC = 0.724). The logit function (y) from logistic regression (coding qualitative variable **Table 2**):

$$y = -27.212 + NH * 0.00035 + LATSS * 0.671 + DL * 0.012$$
$$SCS \begin{cases} NOT = 1.311 \\ YES = 0 \end{cases} + SPR \begin{cases} NOT = 0.847 \\ YES = 0 \end{cases} + SUM \begin{cases} NOT = -0.911 \\ YES = 0 \end{cases}$$

For the LLALB we obtained a model with the variables fisheries over continental shelf (SCS) and Summer (SUM). The model's goodness-of fit-was significant according to the Omnibus test (Omnibus test= 234.174, df= 2, P< 0.0001; Hosmer and Lemeshow test= 15.611, df= 2, P= 0.864), and its discrimination capacity was good (AUC = 0.805). The logit function (y) from logistic regression (coding qualitative variable **Table 3**):

$$y = -6.34 + SCS \begin{cases} NOT = 2.41 \\ YES = 0 \end{cases} + SUM \begin{cases} NOT = 0.877 \\ YES = 0 \end{cases}$$

3.2 Temporal oscillation analysis

For the LLHB we obtained a relationship between the favour CPUE per year (fCPUE) and the NAOw, according to the logit function y:

y (sCPUE)= -2.290+ NAOw* -8.769

The model's goodness-of fit-was significant according to the Omnibus test (Omnibus test= 9.103, df= 1, P= 0.003; Hosmer and Lemeshow test= 4.06, df= 8, P= 0. 852), and its discrimination capacity was outstanding (AUC = 0.92).

For the LLALB we do not obtained any relationship between the favour CPUE per year (fCPUE) and the NAO, however, only nine years were observed with sets standardized.

4. Discussion

Pelagic stingray by-catch presents eco-geographical and temporal distribution patterns. This trend was found to be primarily related with the summer season and fishing activity over continental shelf. Previous studies have shown how different eco-geographical and gear-type parameters heavily influence over the CPUE of pelagic stingray. Santana-Hernández et al. 2011 and Domingo et al., 2005 suggested the correlation between sea surface temperature (SST) and by-catch CPUE; however, there were some discrepancies between the temperatures ranges proposed: 26°C to 27°C and 20°C to 23°C respectively. We have not tested SST as a variable in our models but the highest temperatures occurs in summer (an explicative variable in our two models) in Western Mediterranean. According to our model LLHB is positively correlated with the summer whereas LLALB is negatively correlated with summer. This discrepancy could be related with the seasonality and fishing strategy of each gear; where LLHB is used along the year both in oceanic and continental shelf, LLALB is used more frequently in summer over continental shelf and, in other seasons mainly in oceanic areas.

In both models, setting the gear away from the continental shelf showed to be one of the most important variables which influence by-catch. In agreement with Domingo *et al.*, 2005 our results also showed that the majority of the captures took place in deeper waters further away from the coast; furthermore, this coincides with the oceanic distribution of this stingray species.

Moreover, in the LLHB model the number of hook per set (NH), latitude where the setting started (LATSS), and distance between both extremes of the longline (DL) showed a relationship. In a previous paper about seabird by-catch by Spanish longline Báez et al. (2014a) also observed that these three variables were related with the increase of by-catch probability. Thus, NH and DL are two variables related with observed fishing effort. Thereby, the increase of NH implies an increase of probability of caught. Similarly, the increases of DL imply a major cover sea surface area, which could increase the pelagic stingray by-catch probability. Latitude where the setting started (LATSS) could be related to the differential effort distribution.

For calculate the CPUE per year for the favorable sets (fCPUE) in LLALB and LLHB, we used only the fisheries operation setting out over continental shelf, and the variable summer (in the case of LLHB only fisheries operations setting in summer, while in the case of LLALB only fisheries operations setting in other season). Climatic oscillations caused by the NAO have been shown to influence both marine and terrestrial systems (Ottersen *et al.*, 2001). Our results for both LLALB and LLHB were limited by the small number of years where by-catch data were available for this comparison, nine and ten years respectively. This limited amount of data may have been the reason why no apparent relationship was found between LLALB by-catch and positive NAO years. Nevertheless we did find a negative relationship between LLHB by-catch and NAO years. The effect that NAO has on SST is known to have multiple effects on marine biological communities such as biological recruitment, species distribution or predator-prey interactions (Ottersen et al., 2001). According to Báez et al., (2013b), negative NAO phases could increase SST from Alboran Sea. Moreover, the negative NAO phase favours rainfall and run-off, which increases the contribution of land-based nutrients to the sea, this increase could increase plankton productivity. In this context, the negative NAO phase has been implicated as driver for induced blooms along the coast of the Iberian Peninsula (Báez et al., 2014b). However, given the reduced amount of data available, these effects are difficult to characterize with certainty.

Despite the high levels of indirect exploitation as by-catch in longline fisheries, pelagic stingrays are listed as 'Least Concern' (LC) under the International Union for the Conservation of Nature (IUCN) (Baum et al., 2009). However, removing large quantities of these organisms from the pelagic realm has inevitable ecological consequences. This study presents the first multifactorial analysis of pelagic stingray by-catch by the Spanish longline fleet in the Mediterranean. The findings could not only relate to the Spanish longline fleet in the Mediterranean Sea but in other fisheries worldwide. This type of multifactorial study contributes to a better understanding of the eco-geographic, seasonal and temporal trends which affects this species, which intrinsically affects our ability to increase better its conservation status.

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Table 1. The variables used for tested the relation with the incidence of pelagic stingray by-catch, and corresponding grouping factors.

Factors	*Variables*	*Variables types*	*Abbreviation*
Technical characteristics of the fishery	Number of hooks	Quantitative	NH
	Distance between both extremes of the longline	Quantitative	DL
	Diurnal or nocturnal setting	Binary	DN
	Setting hours	Categorical	SH
	Drifting surface longliners targeting bluefin tuna	Binary	LLJAP
	Traditional longliners targeting swordfish	Binary	LLHB
	American longliners targeting swordfish	Binary	LLAM
	Drifting surface longliners targeting albacore	Binary	LLALB
	Drifting semi-pelagic longliners targeting swordfish	Binary	LLSP
	Bottom longliners targeting swordfish	Binary	LLPB
Interaction with other fisheries	Non-working days	Binary	NWD
Geographical location	Latitude where the setting started	Quantitative	LATSS
	Longitude where the setting started	Quantitative	LONGSS
	Latitude where the setting finished	Quantitative	LATFS
	Longitude where the setting finished	Quantitative	LONGFS
	Sets over continental shelf	Binary	SCS
Seasons	Winter	Binary	WIN
	Spring	Binary	SPR
	Summer	Binary	SUM
	Autumn	Binary	AUT

Table 2. Coding qualitative variable used for the logistic regression model between caught at least one pelagic stingray and independent variables (Table 1) for the case of traditional surface longliners targeting swordfish (LLHB).

		Frequency	*Parameter coding (1)*
SUM	NO	663	1.000
	YES	607	.000
SPR	NO	1174	1.000
	YES	66	.000
SCS	NO	727	1.000
	YES	513	.000

Table 3. Coding qualitative variable used for the logistic regression model between caught at least one pelagic stingray and independent variables (**Table 1**) for the case of surface longline targeting albacore (LLALB).

		Frequency	*Parameter coding*
AUT	NO	749	1
	YES	98	0
WIN	NO	763	1
	YES	84	0
SPR	NO	543	1
	YES	304	0
SUM	NO	486	1
	YES	361	0
SCS	NO	427	1
	YES	420	0

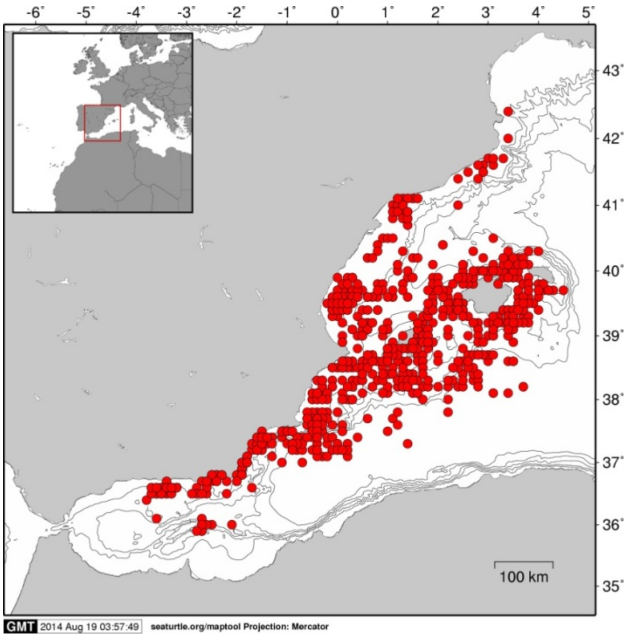

Figure 1. Distribution of the observed fishing operation in traditional surface longliners targeting swordfish (LLHB).

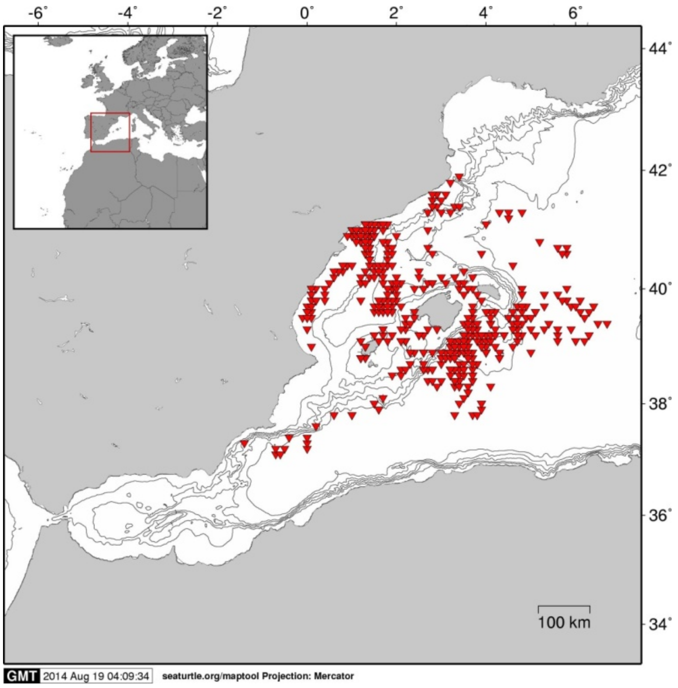

Figure 2. Distribution of the observed fishing operation in surface longline targeting albacore (LLALB).

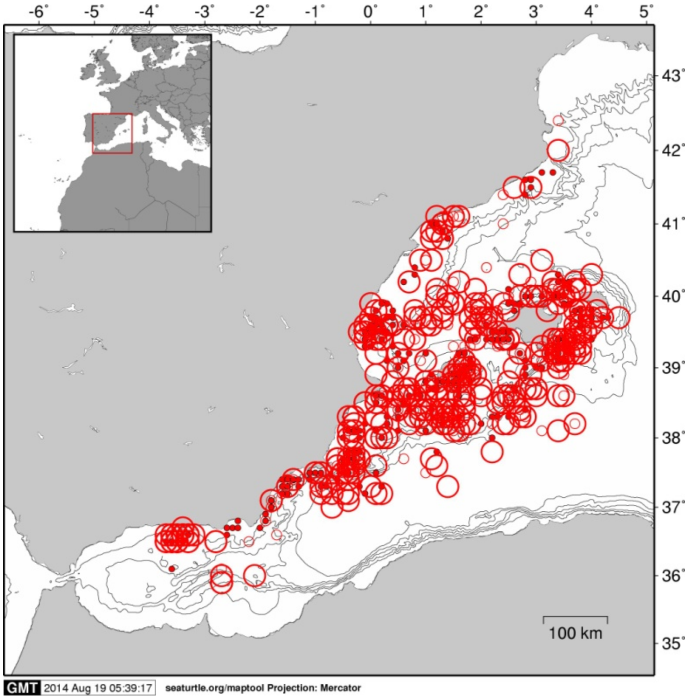

Figure 3. Distribution of the by-catch frequency in traditional surface longliners targeting swordfish (LLHB) per fishing operation. Key: Small circle = catch number ≤ 5 pelagic stingray individuals; Medium circle = catch between 5-10 pelagic stingray individuals; Large circle = catch >10 pelagic stingray individuals.

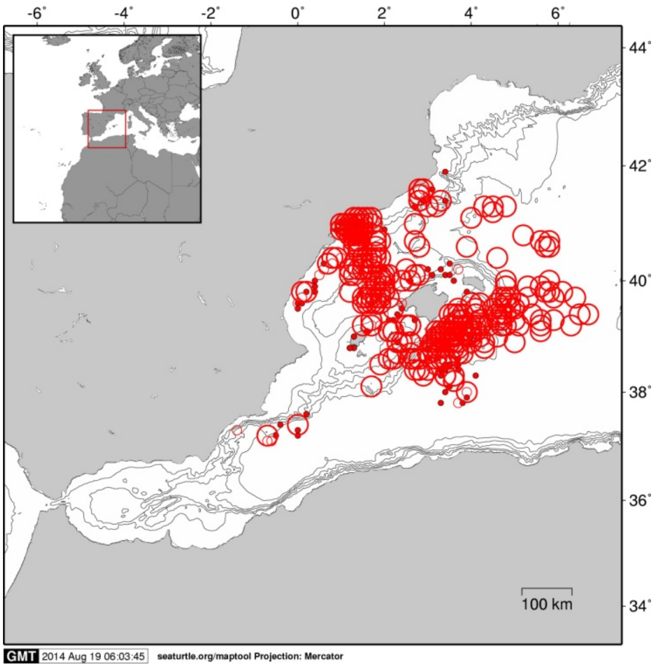

Figure 4. Distribution of the by-catch frequency in surface longline targeting albacore (LLALB) per fishing operation. Key: Small circle = catch number ≤ 5 pelagic stingray individuals; Medium circle = catch between 5-10 pelagic stingray individuals; Large circle = catch >10 pelagic stingray individuals.